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HEAT AND TEMPERATURE IN THEIR RELATION TO WORK

By JOHN ROGER

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HEAT AND TEMPERATURE IN THEIR RELATION TO WORK.

In dealing with heat and work at least in mechanical and engineering problems it has always seemed that if the subject were treated from an entirely different standpoint from that now used it could be greatly simplified and made much more understandable.

If we consider heat as a definite entity and temperature as a condition of that entity, *i. e.*, temperature as a measure of heat density or stress in precisely the same way as we consider electricity by amperes (quantity), and volts (pressure), we can with a proper scale of temperatures get a clearer and a simpler view of the relationship between work and temperature.

As we estimate the work in a unit of gas

from the initial pressure to the zero of pressure, so we should estimate the work of the unit of heat from the initial temperature to the zero of temperature. The two cases are practically identical and the two zeros are probably approximately one and the same, when the gas is expanded adiabatically.

The words, Heat, Unit of Heat and Temperature being used in this paper in a different sense from that usually applied to them, the following explanation may serve to convey more clearly what the words as used mean.

Heat.—A general expression used as we now use the words "electricity" or "current" in electrical science.

Unit of Heat.—Used as we now use the word "ampere" in connection with electricity; being the amount of heat necessary to raise one pound of water from 40° F. to 41° F. This amount of heat acting through one power degree, as shown on scale Fig. 3, equals about 4.677 foot pounds of work, or 693 foot pounds of work acting from

41° F. to zero of work temperature in steam expanded adiabatically.

Temperature.—This word is used both as temperature Fahrenheit and as power or work temperature, as shown on scale Fig. 3. In the scale Fig. 3 the degree would be similar to the volt in electrical science, in short, one unit of heat acting through one power degree is equal to 4.677 foot pounds in expanding steam as figured.

It is assumed that a given quantity of steam by weight, at whatever pressure in expansion, contains the same amount of heat so long as there is no radiation or induction, and that increase in pressure is due to forcing the molecules or groups closer together, producing molecular stress, and that the power temperature is the measure of this stress.

To assist in demonstrating the above idea, I have prepared two scales which are herewith shown, and submit these, feeling that they are of sufficient interest to warrant some study.

It may be here stated that the adiabatic expansion of steam as usually given is evidently wrong and this is borne out in practice. An engine with a well lagged cylinder will show a higher terminal pressure than that developed from the adiabatic curve and this despite the fact that considerable radiation must take place. The true adiabatic expansion would probably follow very closely the pressures and volumes given in accurately determined steam tables. The ratios used in calculating the work values in the scales herewith may give too high results, but the error over the range of workable pressures cannot be very great, although this error might considerably modify the point at which complete relaxation takes place.

That increase and decrease of temperature in compression and expansion may have nothing to do with increase or decrease in the quantity of heat will be considered later.

Work Scale by Pressure

The law by which steam expands seems in practice very much more complex than it really is, due to radiation, induction, etc., which affect results, and we may construct a scale of power relative to pressure which, while not accurate, will serve to illustrate expansion in a very graphic way.

Referring to Fig. 2, let AB be a straight line divided into equal intervals, each interval representing one pound pressure per square inch. Beginning with 250 pounds absolute pressure, and assuming one pound of steam as our quantity, we expand this steam adiabatically to double its volume, reducing the pressure to 120 pounds per square inch, and at those pressures draw the lines CD and EF.

The foot pounds of work developed in this expansion will be about 45,288, and if we decide to make the power degrees on our scale 5,000 foot pounds each, then there will be 9.057° between the lines CD and

EF. We may bisect this distance and lay off GH, equal to one degree, being the average length of the 9.057° above referred to. If we again expand the steam to double its volume, that is, from 120 pounds to 57.6 pounds, and draw the line LM at 57.6 pounds pressure, the work in this expansion will be about 43,476 foot pounds, or equal to 8.695° between the lines EF and LM, and we can thus lay off the average degree in this expansion at NO in the same way as before. If we draw the diagonal line PQ through these points we will have a diagram in which intervals laid off by geometrical progression, as at R, will each show very closely equal degrees of work, that is, a given quantity of steam expanded between the intervals shown will develop equal amounts of work for each degree throughout the scale. The other expansions may be laid off down the scale for verification and will check up very closely, but slight errors will appear, these, no doubt, due to the steam tables of volumes and pres-

sure not being quite accurate, the line PQ should probably be slightly curved.

The total number of power degrees in the full expansion to the Fahrenheit temperature 32° will be about 80.75; and 8 pounds absolute will be just about half way on the scale, so that in practice if we expand steam from 250 pounds pressure to 8 pounds absolute, we get just about 50% of the work in the expansion; if the surrounding temperature is 32° F. the back pressure is assumed to be nil and the loss is due to incomplete expansion.

To estimate the loss of energy in expanding steam by taking the number of pounds of water, which it will increase so many degrees in temperature Fahrenheit when condensed, and therefore so many units of heat lost at 774 foot pounds per heat unit, is very misleading. There is no difficulty in heating water, say 10° above its normal Fahrenheit temperature, with an expenditure of work less than 20% of 774 foot pounds per unit of heat, and the amount of

water so heated would be limited only by the size of the apparatus we might choose to construct.

The proper basis for estimating the dynamic value of steam, would seem to be with reference to the completeness of its expansion, down to the surrounding temperature as the work in expansion below this temperature is not available work, but we must give full consideration to the state of the steam dealt with, as we do not get equal amounts of available work from one unit of heat, expanded through a given short range of Fahrenheit temperatures under all conditions.

In steam the work is done by the so-called latent heat of expansion, each unit of heat representing about $\frac{1}{1069}$ of the volume in one pound of steam at 41°, while with superheated steam each unit of superheat added represents an addition of about $\frac{1}{492}$ to the volume, hence their relative expansive value

at this temperature is about as 4 is to 1, if we assume the specific heat of steam to be .543, and from this relationship the expansive force of superheated steam can be determined.

Having shown the regularity of expansion in steam with reference to the pressure scale, let us now consider its expansion from a different standpoint, that of work. It may be stated that the Fahrenheit scale is a uniform scale of temperatures in matter only when no change of state occurs as the heat is added; it may be used as a measure of quantities of heat, but only so under certain well-defined conditions. Power temperature is the measure of the condition of a given quantity of heat, through changes by expansion. The Fahrenheit temperature changes in a gas and a vapor in expansion are entirely different. Let us, therefore, construct a scale of power temperature and apply our steam expansion thereto.

Power Scale by Temperatures

To construct a scale of temperatures such that each degree will represent an equal amount of work, we can do so diagrammatically with close approximation, but data is not available to give the same accurately.

Referring to Fig. 3, let AB be a straight line divided off into equal intervals and assume that each interval represents 5,000 foot pounds of work in one pound of steam expanded adiabatically through each power degree. Let us take a line CD at the top of the scale, at the temperature equivalent to 250 pounds per square inch. To expand one pound of steam from this temperature to double its volume the pressure will drop to 120 pounds per square inch, and the work done in expansion will be about 45,288 foot pounds, or equal to 9.057 degrees on the scale at 5,000 foot pounds to the degree.

By continuing to expand the steam by doubling its volume and figuring the me-

chanical equivalent for each expansion, we can determine the divisions EF, GH, IJ, KL, MN, OP, QR, ST, UV, with their equivalent of pressure and work as noted on the scale. Now, if we lay off the line CD, equal to the interval between CD and EF, and again the line ST, equal to the interval between ST and UV, and draw a diagonal line connecting these points, we will have a diagram showing the direct progression of power temperature change in the expansion, *i.e.,* the direct relation of the repulsive force between the groups of molecules in the expansion.

Let us extend the diagonal line until it cuts the line of power temperatures. Does not the intersecting point between these two lines indicate very closely the zero of work temperature in the vapor? *i.e.,* the end of the work cycle, *i.e.,* the point where work in expansion ceases, *i.e.,* the point at which molecular repulsion is neutralized by mass attraction.

The line BD might not, in fact, be a

perfectly straight line, but it would be so nearly straight at the points corresponding to workable pressures that the difference would be very slight. If the diagram was worked out to show the true curvature, and the scale divisions laid out on the central axis of the figure similar to Fig. 5, this would, no doubt, change the zero point some and would probably decrease the number of power degrees in the expansion.

The total number of power degrees between 250 pounds pressure and the zero just determined is about 226.3, which, at 5,000 foot pounds to a degree, equals 1,131,-500 foot pounds of work in the total expansion.

If we now determine where the temperature 41° F. comes on the scale, which we can do quite closely, we will find that from 41° to zero on the scale gives about 148.3 power degrees, which, at 5,000 foot pounds to the degree, equals 741,500 foot pounds.

To this amount we will require to add the work of deplacement of the vapor at

41° F., equal to about 43,000 foot pounds, making a total work of 784,500 foot pounds.

If we now consider that all the heat in one pound of water at 40° F. the temperature of greatest density is necessary to neutralize the attractive forces in the matter. In other words, that the liquid is that condition of matter wherein the attractive and repulsive forces completely neutralize each other and that the only heat which develops work expansively in the vapor is the so-called latent heat of vaporization, or the heat from which we derive the expansion, we will therefore have about 1,069 units of heat in one pound of steam which are active, and if we divide the 784,500 foot pounds indicated on the scale by 1,069 we will have the mechanical equivalent of one unit of heat expanded from 41° F. to zero, including the work of displacement, equal 734 foot pounds.

Is it therefore improper to say that in steam the mechanical equivalent of one B.T.U. is the work done by that amount

of heat expanded through the medium of steam from 41° F. to zero of power temperature, as in dealing with steam this is the total work obtainable from one unit of heat? The temperature of complete relaxation may be somewhat above the absolute zero and the work derived from the complete expansion would be less than the total work of the heat unit. As the vapor is supposed to be still distended the molecules must retain their repulsive force to maintain the distention, so they must retain the same amount of heat as they started with.

That the Fahrenheit scale, as far as it relates to steam temperatures, has no close relation to the scale just described is evident. The average dynamic value of the Fahrenheit degree between 250 and 120 pounds pressure is about 757 foot pounds, while the average dynamic value of the Fahrenheit degree between .7113 pound pressure and .3418 pound pressure is about 1,463 foot pounds, or almost twice the number of foot pounds for one degree reduction

of Fahrenheit temperature in one pound of steam by expansion at the lower pressure.

That the value of the B.T.U. should work out at a smaller figure than the ordinarily accepted amount does not refute the accuracy either of the above determination, or of the generally accepted mechanical equivalent of the B.T.U. for the reason that the work derived from expansion must be less than the total value of the heat unit at least by the amount of work necessary to pull the molecules apart, also we have withdrawn no heat from the vapor, but have simply reduced the temperature by expansion. The absolute zero can only be attained by withdrawing the contained heat.

If the vapor expanded continuously, according to the Marriote law the lines in the diagram would be parallel as at DW, and the intervals of expansion on the scale would be equal, an evident impossibility, as this would mean expansion to infinity and infinity of work.

Isothermal expansion is not the expansion of a definite quantity of gas, but of a quantity of gas continually augmented by additional heat, intensifying the repulsive forces and causing these to vary inversely as the distance between the molecules.

When we differentiate between heat and temperature we must also differentiate between zero of temperature and zero of heat, or absolute zero. When we reduce the heat density in a mass of material to zero by withdrawing the total contained heat, the operation is different from that of producing zero of power temperature in expansion wherein no heat is removed. The decrease in temperature by expansion is due to the moving apart of the molecules or increase in volume.

With the scales shown, all that is necessary is to determine the quantity of steam dealt with, the initial and terminal pressures to get the theoretical work done by the steam in expansion.

To produce an accurate, practical work-

ing scale on the above basis, it would be necessary to determine most of the factors involved more accurately and also make the diagram larger, so that the power degrees could be greatly sub-divided. It might also be desirable to change the sub-divisions on the scale to indicate that one unit of heat expanded through one power degree equals one foot pound, or better still, to give all the factors a decimal relationship. The quantities could be readily calculated and a table compiled which would give much greater accuracy, but the diagrams show very graphically what the relations of work, volume and pressure are.

The correct geometrical figure by which to show both scales would probably be similar to that shown on Fig. 5, using the central axis on which to indicate both the pressure and the power scales.

That change in temperature by normal compression or expansion, without friction or impact, has nothing to do with increase or decrease in quantities of heat, but is

simply change of stress, can easily be shown. Expansion of a gas is in fact a simple mechanical operation easily defined.

Suppose we take a quantity of steam at a hundred pounds pressure in a cylinder. The steam contains so many molecules repelling each other with a given force. Let us say there are four thousand molecules to the square inch acting on the surface of the piston. If we now expand the steam to eight times its volume the average distance between the molecules having been doubled, there will then be only one thousand molecules per square inch pressing on the piston, so thereby the pressure has been divided by four, or reduced to twenty-five pounds per square inch. But we have still another factor to deal with, the molecules have moved farther apart, the average distance between them has been doubled, and as their repulsive force decreases inversely as the distance, therefore the pressure falls below 25 pounds by this increment of decrease, that is, to one-half of 25 pounds equal to

12.5 pounds per square inch; this is isothermal expansion.

There is still a third factor to be considered, which we may call mass attraction, or the work necessary to pull the molecules apart, and therein we have adiabatic expansion. Diffusion can only continue to that point where the molecular repulsion is equal to the mass attraction, and there the forces would be in a state of equilibrium. We might characterize the third force as an opposing force acting similarly to back pressure.

The reverse of the above would take place in compression, so it seems perfectly safe to say that temperature is increased in compression by forcing the molecules closer together; increasing the molecular stress and the power temperature is simply the measure of this stress.

That vaporization and the pressures of vapors are due to molecular repulsion seems evident. The two forces of attraction and repulsion are simply positive and negative

forces acting through molecular relationship.

In dealing with the expansion of vapors in the ordinary way great complication arises from dealing with factors which change their relationship to each other with every change in expansion or compression. The relationship between volume and pressure can be clearly presented through spherical relationships.

If we take a hollow sphere 12 inches in diameter, filled with steam at a hundred pounds pressure per square inch, we have a fixed number of molecules repelling each other with a definite force and the molecules or groups are at a definite fixed distance apart. The internal surface of the sphere will be 452.39 square inches, so the total pressure on the inside of the sphere will be 45,239 pounds. If we now consider the sphere expanded to 24 inches in diameter we have increased the volume eight times, or the pressure per square inch has been reduced to $100 \div 8 = 12.5$ pounds per square

inch, by isothermal expansion, and the average distance between the molecules has been doubled.

To analyze the pressure change. The internal surface area of the 24 inch sphere will be about 1809.6 square inches, which multiplied by the 12.5 pounds pressure per square inch, will give a total internal pressure on the 24 inch sphere of 22,620 pounds, or one-half of the total pressure on the 12 inch sphere, and this is the true pressure relationship in isothermal expansion. As the same number of molecules are pressing outwardly in both cases, therefore the outward pressure due to the groups of molecules is inversely as their distance apart.

Referring to Fig. 4, the 12 inch sphere is shown, and we assume that there are so many molecules pressing on the sector AB equal to one square inch area to give 100 pounds of pressure, let us say there are 4,000 molecules pressing on this surface. When we expand the sphere to double its diameter the 4,000 molecules will then press

on the sector CD with an area of four square inches and the pressure on this sector will be 50 pounds, so, if we divide the 50 pounds

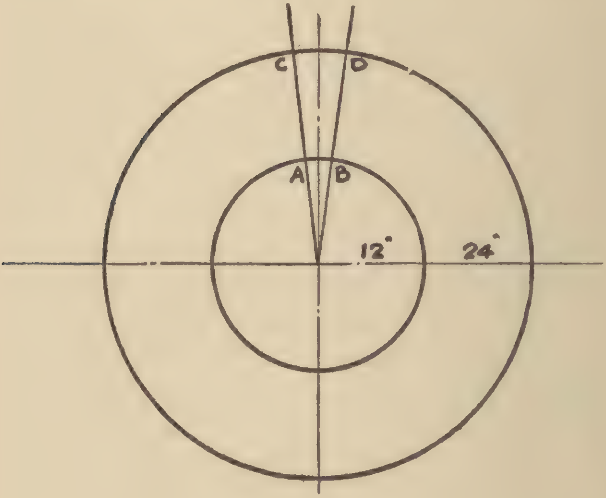


FIG. 4

by 4 to give the pressure on one square inch of the sector CD we will then have a pressure of 12.5 pounds exerted by one-

fourth of the number of molecules, or 1,000. The pressure having been considered isothermally for convenience.

Isothermal expansion, or its equivalent, that the pressure per square inch should change inversely as the volume cannot occur in the expansion of any gas or vapor continuously, for the reason that we cannot get infinity of expansion or infinity of work from a given quantity of gas, as all forces must become neutralized at some point to produce stability, and so the expansive force of steam or gas becomes neutralized by what we have called mass attraction.

What is meant by this term may be explained as follows: In a gas at say 100 pounds pressure, the molecules have a certain spacing relative to each other and the molecules attract each other with a given force, this force being neutralized by the force of molecular repulsion. When the repulsive force is greatly in excess of what is necessary to overcome the force of attraction, then we have the outward pressure.

When the gas is expanded the molecules are lifted away from each other, just as we would lift a weight from the surface of the earth, and this requires work in foot pounds which must come out of the expansive force of the gas. The force necessary to separate the molecules decreases inversely as the square of their distance apart. In gases the force of repulsion between the molecules also decreases inversely as the square of their distance apart, so we have the work necessary to force the molecules apart, always being augmented as the molecules recede from each other, while the work of the repulsive force producing the pressure is similarly being decreased, hence adiabatic expansion.

To show that in the adiabatic expansion of a gas the pressure varies inversely as the square of the distance between the molecules, or atoms, let us take air, an approximately perfect gas, and referring to Fig. 4, let us suppose the 12 inch sphere is filled with air at 214.7 pounds pressure per

square inch. The total surface pressure inside the sphere will be 97,128 pounds. If we now expand the air adiabatically to fill the 24 inch sphere and figure the pressure to decrease inversely as the square of the distance, then the total surface pressure inside the 24 inch sphere will be 24,282 pounds, or 53.6 pounds on the sector CD of 4 square inches, which will make 13.4 pounds per square inch pressure.

The air pressure resulting from the above expansion as given in standard table is 11.5 pounds per square inch, or about two pounds less than that deduced from the ratio of expansion given. This difference is probably all due to mass attraction, or the work necessary to pull the atoms apart, and which work reappears in compression.

In dealing with pressure in the expansion of gases to take the unit of measure as the pressure on one square inch of surface is very misleading, for the reason that the number of atoms pressing on one square inch is continually changing, as the expan-

sion progresses, and hence the curved expansion line on the indicator diagram, and to the use of this curve we may ascribe much of the confusion which befogs the subject. The curvature of this line is not due to any peculiarity in the expansion of the gas, but to the continual decrease in the number of atoms acting on the piston of the indicator, as the expansion progresses. If we take the total internal pressure on the total surface of expanding spheres, we get the true pressure change and relationship, and this change is inversely as the square of the distance between the atoms, modified by the mass attraction. These pressures might be characterized as spherical pressures, as the pressures vary very nearly inversely as the surface areas of the enclosing spheres in the adiabatic expansion of a gas.

The atomic repulsion in a gas in adiabatic expansion follows the same law reversed as the attraction of gravity, the forces being simply positive and negative. It must be remembered that when we deal with ex-

pansion of gases we are dealing with infinitesimally small distance between the atoms, even in the most complete expansion possible.

In the expanded gas we may say that we have just as much heat as we started with, the potential of the atoms remaining practically the same, but we have reduced the temperature, *i.e.*, the stress, *i.e.*, the heat density in the volume, and the work done is the resultant of this reduction of stress.

It should be noted that the Fahrenheit temperature change in a gas expanded adiabatically conforms very closely with the power scale of temperature given in Fig. 3. The degrees, however, being of different size. This similarity is no doubt due to the fact that in adiabatic expansion a gas follows the correct law of forces in repulsion, the force varying inversely as the square of the distance between the masses.

It may be claimed that these scales being similar, why not use the Fahrenheit scale instead of making another, and no doubt

this could be done, but we would have to abandon the temperature scale in the case of expanding steam.

The pressure of a gas or vapor is therefore due simply to the molecules repelling each other, the temperature in a gas being the measure of the stress of this force, and as the pressure is relaxed, *i.e.,* the molecules move farther apart in expansion, the temperature decreases as the stress is reduced. That these forces do not act to infinity must be evident, otherwise any quantity of gas, however small, would have infinity of expansion and develop infinity of work.

In a perfect gas the potential is practically constant and the force follows the same law as that of gravitation reversed, this, however, being slightly modified by the mass attraction or the work necessary to pull the molecules apart, which force produces neutralization of the pressure when a certain degree of expansion has been reached. It seems true, however, that one unit of heat expanded to zero will give the same amount

of work whether figured by the law of expanding gases or of vapors.

To determine the amount of work to be derived from one unit of heat by expanding air from 33° F. The specific heat of air at constant pressure being .2375 and one pound of air at 14.7 pounds absolute pressure being equal to 12.4122 cubic feet, then 52.26 cubic feet of air will have a specified heat of 1. By raising the temperature of 52.26 cubic feet of this air one degree, we add one unit of heat and increase the volume $\frac{1}{492} = 52.26 \div 492 = .106$ cubic foot $=1$ unit of contained heat. The displacement work of .106 cubic foot would be $144 \times 14.7 \times .106 = 224.7$ foot pounds. If we now take the .106 cubic foot of air at 33° F. and expand it to zero, the work in the expansion would be about 538.7 foot pounds, thus we have $224.7 + 538.7 = 763.4$ foot pounds as the total work in the one unit of heat expanded from 33° to zero. One unit of heat expanded through one Fahrenheit degree

equals about 1.09 foot pounds in air. Considering the number of figures involved, also the number of quantities and ratios taken, all of which are no doubt more or less inaccurate, the figures come out close enough to indicate that the method followed is practically correct. A work diagram of the above expansion would be about as shown in Fig. 5. The lines AC and BC would not perhaps be perfectly straight, but for simplification they have been shown so. If accurately figured, on the proper curvature giving the correct pressure ratios, the work equivalent would no doubt be modified to some extent.

A gas can only expand till the forces are neutralized, or to where complete relaxation takes place, and therein we have adiabatic expansion, the only true expansion of a fixed quantity of gas or vapor.

The reason why the spherical pressure in a vapor varies inversely as the distance between the molecules while in a gas it varies inversely as the square of the distance, is

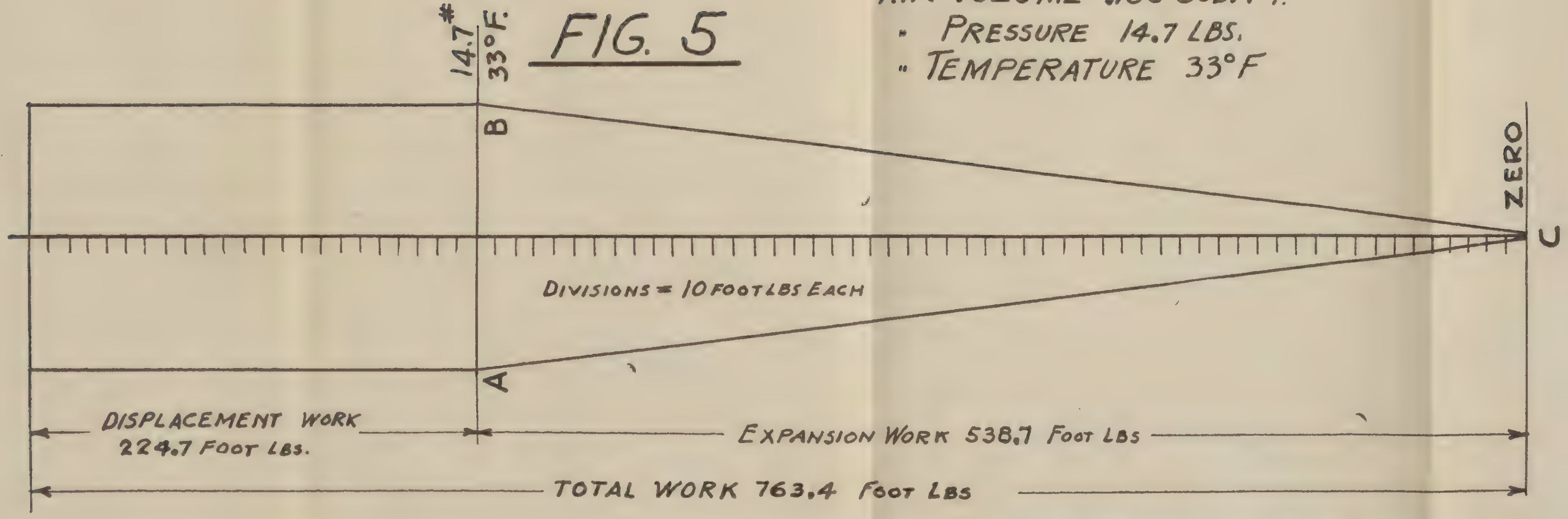


FIG. 5

AIR VOLUME .106 CUB. FT.
" PRESSURE 14.7 LBS.
" TEMPERATURE 33°F

WORK DIAGRAM OF ONE UNIT OF HEAT
ACTING THROUGH AIR AS A MEDIUM

John Roger
Nov. 2nd 1915

not very clear, but it is probably due to the molecules in the vapor being combined, the groups varying the potential in expansion. An explanation may be found in assuming that disgregation in the vapor is incomplete, and that the molecules are repelled not singly, but in groups or clusters. The size of the cluster depending on the pressure, increasing in size up to the point of critical pressure, where the groups are at their maximum, but these clusters decreasing in size with expansion as the pressure is relaxed down to a point in complete diffusion where the vapor would become a perfect gas, where disgregation is complete.

The groups would thus at all times be at a critical point, so that any radiation of heat, at whatever pressures, would produce condensation of part of the vapor, so as to re-establish equilibrium.

Superheating steam would therefore mean that by adding heat to the vapor we increase the repulsive force of the individual molecules, gradually breaking up the

groups, and when sufficient heat has been added, the groups will be completely broken up—disgregation being complete.

In dealing with the work to be derived from expanding vapors or gases, no consideration has been taken of the displacement work on the scales, because this work does not result from any heat or temperature change in each volume of vapor or gas segregated for expansion in an engine. The displacement work, or the work derived from filling the cylinder, is the result of the stored-up energy in the whole mass of gas or vapor affected by the displacement acting expansively. It is the difference between producing a volume of vapor at high pressure from the zero of pressure by adding heat at a steadily increasing temperature and the production of a similar volume at a uniform pressure requiring a uniform temperature in the heat transferred, plainly indicating that to deal with heat in producing work, we must deal with it relative to its power temperature.

In dealing with steam for power purposes, due to the sluggishness of heat in transferring from one substance to another, we find in practice that it is desirable to divide the process of expansion into two operations, one of which is done in the boiler; from this we get the work of displacement in the engine without changing the spacing of the molecules, the other is the work of expansion in the engine which relaxes the stress between the molecules, increasing their distance apart. A perfectly operative engine can be constructed wherein the total expansion would be in one operation, when the evaporation would take place in the cylinder.

That there is no warrant for dealing with heat on the basis now generally used can be clearly shown by a simple demonstration whereby performing the same act in different ways gives entirely different results.

If we take two cylinders, A and B, Fig. 6, each 144 square inches in area, each fitted

with a piston and filled with one pound of steam at 250 pounds pressure.

In the case of A let us expand the steam to twice its volume, or to a pressure of 120

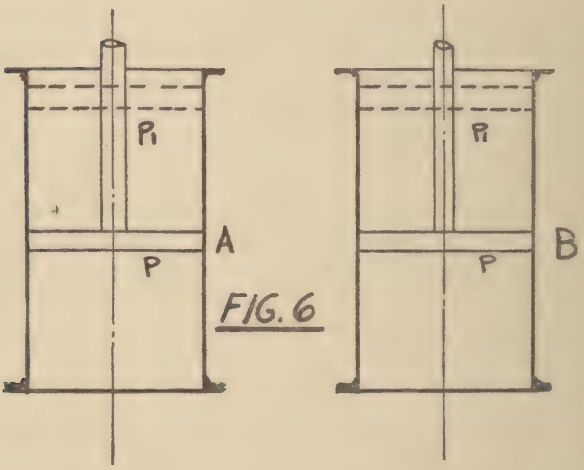


FIG. 6

pounds per square inch, by raising the piston to P i. The work given out in this expansion will be about 45,288 foot pounds. Let us now superheat the steam to get 250 pounds pressure, we, according to accepted

tables, will have to add about 370 units of heat.

In the case of B let us superheat the steam at 250 pounds pressure to give double the volume, the piston will rise to the new position and develop 66,600 foot pounds of work, and we will require to add to the steam about 359 units of heat.

The two operations were started under precisely the same conditions and finished precisely the same, but in A we have provided 370 heat units and got 45,288 foot pounds of work, while in B we have provided only 359 heat units and got 66,600 foot pounds of work, we therefore are out on the A operation 11 heat units and 21,312 foot pounds of work, an evident absurdity.

The facts would seem to be that we lost no heat when we expanded the steam in A, what we did lose was temperature or stress, and by reason of superheating A at a lower average of temperature or stress it would require the equivalent of 21,312 less foot pounds of work to complete the

superheating than in the case of B where the entire superheating had to be done at the full 250 pounds pressure. In other words, sensible heat does not change in quantity in expansion, but it loses its temperature or density down to the point of neutralization, just as in air and other gases. The work derived from an expanding gas is therefore simply mass in distance measured through the forces of repulsion, the potential of the molecules remaining practically the same. In a vapor the factors, pressure temperature and volume, are relatively constant, because the heat cannot be changed in quantity without disturbing the grouping of the molecules, but in a gas all three factors may change relative to each other over wide ranges, because the contained heat can be changed in quantity without producing change of state.

The above remarks are intended to outline in a general way how we may deal with heat as a fixed entity, beginning at the zero of temperature, changing in density

as temperature is increased and its capacity to perform mechanical work being proportionate to its density or power temperature.

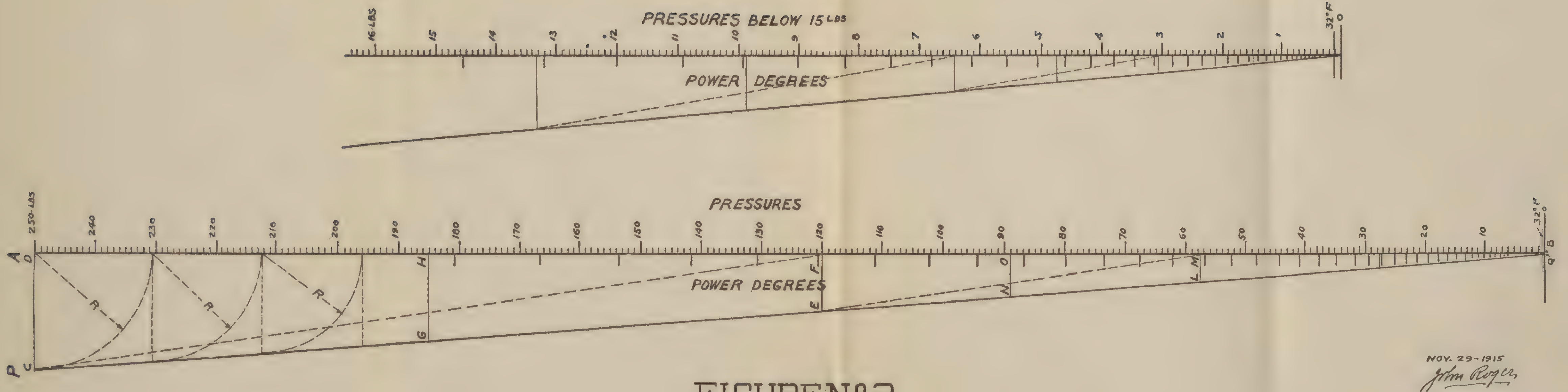
If we admit that the unit of heat exists as a definite entity from the zero of temperature and is expandable through a proper medium from any density back to that zero, then we must admit that we produce heat by friction from that zero, and that less power would be required to produce one unit of heat at 100° temperature than would be necessary to produce one unit of heat at 200° temperature proportionate to the number of degrees power temperature; also that when we compress a gas without friction or impact we make no additional heat, but we increase the temperature by pressing the molecules closer together. When we increase the temperature of a gas by adding heat to it, we add something which afterward manifests its presence both in expansion and compression and the gas can only be returned to its original state by withdrawing the added heat, but when we in-

crease the temperature of a gas by compression, it returns to its former state as soon as the pressure is relaxed.

When we expand a gas without resistance, the friction and impact of the atoms produce additional heat which in part is added to that already present, hence the conservation of energy in expanding gases becomes plainly evident.

When we do measure the highly elusive electric current, with great simplicity and directness by amperes and volts, why do we not measure the much more stable "heat" in a similar way.

From this viewpoint, the science of practical thermodynamics seemed to me to be so simplified as to come within the comprehension of most any one, which it certainly does not in its present accepted form.



PRESSURES BELOW 15 LBS
POWER DEGREES
PRESSURES
POWER DEGREES
250 LBS
32° F
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FIGURE Nº 2

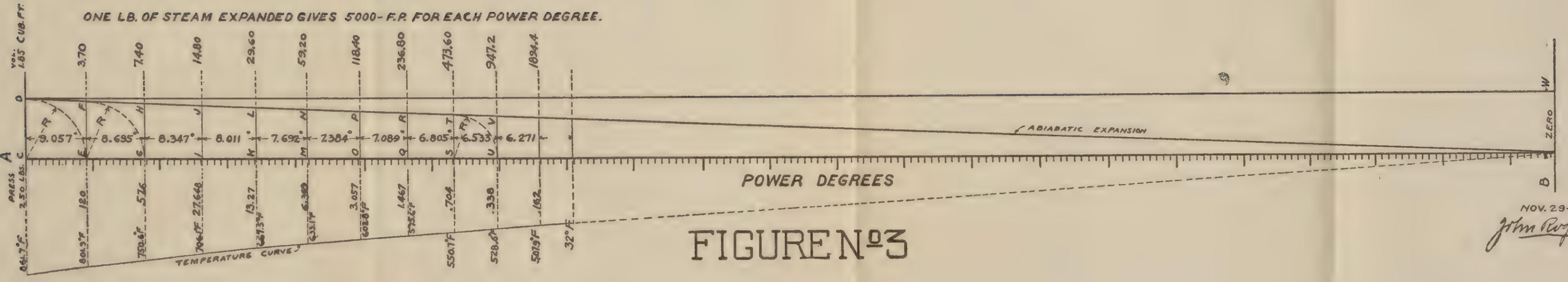

FIGURE Nº 3

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